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RADAR OBSERVATION OF VENUS

by

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ABSTRACT AND TRANSLATOR'S COMMENTS

The present paper is a concise account of the final results of radar observations of Venus conducted in April 1961 by the Institute of Radio Engineering and Electronics of the USSR Academy of Sciences.

There have been several preliminary papers on this research, including newspaper columns (see references). The principal author, V. A. Kotel'nikov, made a personal delivery of a longer paper during the XIIth International Astronautical Congress, held in Washington in October 1961. At that time a preprint was released, and copies - circulated at NASA. This paper has been reproduced anew and attached herewith. It must be pointed out though, that preliminary data included incorrect values of the astronomical unit, upon which the preliminary papers were based. The ambiguity was discovered by way of comparing the earlier published data on the astronomical unit determined by different methods, – the Doppler shift of the narrow-band component and the delays of the reflected signals. Analysis by means of narrow band was not originally made.

In this experiment the radar transmitter operated at a frequency of ~700 mc/s. Power density was 250 mw/sterad, which yielded 15 w on the planet's surface. The polarization of the transmitted waves was circular, and that of the receiving antenna – linear. The transmitted signals were rectangular pulses of 128 or 64 msec and were separated by intervals of the same duration. (details concerning the instrumentation are given in the prinicpal author's paper, presented below).

Analysis of the reflected spectrum showed that the signals could be represented as the sum of narrow-band and wide-band components. The width of the formar was determined mainly by amplitude modulation and did not exceed several c.p.s., while that of the latter amounted to several hundred c.p.s. The astronomical unit was found to be 149, 598, 000 km with an RMS error of 3300 km, using the Doppler shift method, and 149, 599, 300 km with an RMS error of 570 km by the method of reflected signals' delays.

The rotation period of Venus exceeds one hundred 24-hour periods.

The considerations relative to the value of the astronomical unit are illustrated in the Figure below (Fig. 4 of the original Russian text)

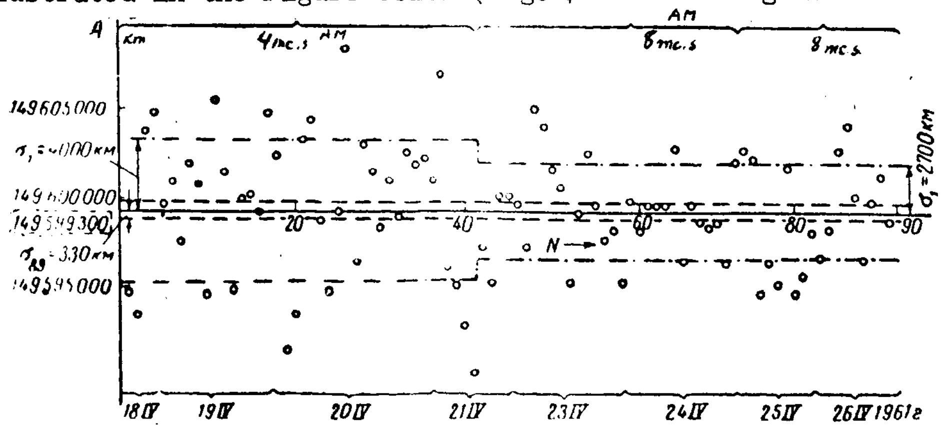

Fig.4. Values of the astronomical unit obtained by signal delay according to separate 5-minute sessions.

Because of the periodicity of the utilized signal, its time lag and the astronomical unit were obtained ambiguously. Thus, the astronomical unit was 149, 599, 300 ± Ln, where n is a whole number and L is equal to 120,000 to 130,00 km for pulses with a period of 256 msec, depending upon the day of observation. As stated, the ambiguousness was uncovered by two methods: by collation with the value of the astronomical unit, obtained by spectrum Doppler shift, and by the constancy of the obtained value at different days. Had the ambiguousness been discovered incorrectly, the value of the astronomical unit between 18 April1961 and 26 Apr. 1961 would have varied by the quantity ~11,000 km or more, hich was not the case, as may be seen from Fig. 4.

/There is no doubt that the presence of the narrow-band component is due to reflections of the transmitted signals from the surface of Venus, while the wideband component, which has not been detected by other researchers, is presumably caused by reflections from formations in the vicinity of Venus/. The parameters of the narrow-band component obtained by us, agree well with those observed in 1961 by other authors [3 - 5].

The author considers that it is most probable that the wideband component originates either from Venus surface reflection, or from reflection of some formations in its vicinity. Two possible variants are condidered:

A. The wideband component is formed as a result of signal reflection from the whole surface of Venus and the Doppler shift caused by its rotation. The narrow band component is caused by reflection of the closest parcel of Venus' surface relative to us (brillant point).

Inasmuch as the widening of the spectrum lines is the narrow-band component at least 100 times less than in the wideband, it must be assumed that the dimensions of the "brillant point" are less than one hndredth of Venus' diameter. This may be, provided the surface of Venus is substantially smoother than that of the Moon.

In the given assumption, and for blurring of the lines at ± 200 mc/s the period of Venus rotation must be near 10 days, provided its axis of rotation is directed perpendicularly toward the Earth and reflects all its surface. If it is directed at 60° [6], the period is shortened to 9 days. But if not all the spectrum was registered, and it is in realtiy wider than 400 mcs, the rotation period must be still smaller.

B. The reflecting properties of Venus are about the same as those of the Moon. Then, similarly to the Moon, the narrow-band component of the reflected signal must correspond to the reflection from a point with one tenth of Venus' radius. Taking into account in this case, that according to our data this component is 4 mcs, we obtain a rotation period of more than 100 days.

At this variant the wideband component cannot be explained by reflection from the surface of the planet, and it must be assumed that that it took place as a result of the reflection of some formations, moving relative to Venus at velocities $\pm$ 40 m/sec or even faster, possibly for example, from strongly ionized fluxes. However, in this case the ionization of these fluxes must be much greater than in the Earth's ionosphere.

The latest data [7], point to that possibility.

Radiotechnical and Electronical
Institute of the USSR Academy of Sciences

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10 October 1962.

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RADAR CONTACT WITH VENUS *)

by V. A. Kotel'nikov

Radar contact with Venus was made in the Soviet Union in April 1961. The purpose of this experiment was to determine more precisely the Astronomical Unit, the major axis of the Earth's orbit, the rotation period of Venus, as well as to obtain data on the structure of its surface.

In this experiment the transmitter frequency was about 700 mc/s. The power flux density was 250 megawatts per steradian, which gave 15 watts on the surface of Venus. The transmitted waves had a circular polarization. The receiving antennas were linearly polarized.

The transmitted signal had the form of square pulses, 128 or 64 ms**) long, with intervals of the same duration. At times, in place of an interval, a pulse of the same duration was transmitted, but at another frequency.

Corrections were introduced in the signal and in the modulation frequencies ised in transmission to account for the Doppler shift caused by a change in the distance from the Earth to Venus, and also by the rotation of the Earth. The frequencies of the transmitter, its modulation and the frequencies of the receiver heterodyne oscillators were derived from a precision-type crystal oscillator ensuring a greater stability than one part in 10^9.

The transmission was carried out during the time for the signal to travel from the Earth to Venus and back again, say about 5 minutes. During about the same subsequent period, the equipment was switched for reception.

A simplified diagram of the transmitter is shown in figure 1 next page. The following designations are used in this figure : MO is the master oscillator, DC is the Doppler shift frequency corrector, FM is the frequency multiplier, T is the transmitter, D is the frequency divider whose oscillations control the key K_2 modulating the signal. The key K_1 is used to start and stop the transmission, and works from the timer T_m which has a precision to 1 ms.

*) Paper presented at the XIIth International Astronautical Congress in Washington D.C., on 5 October 1961.

**) milliseconds

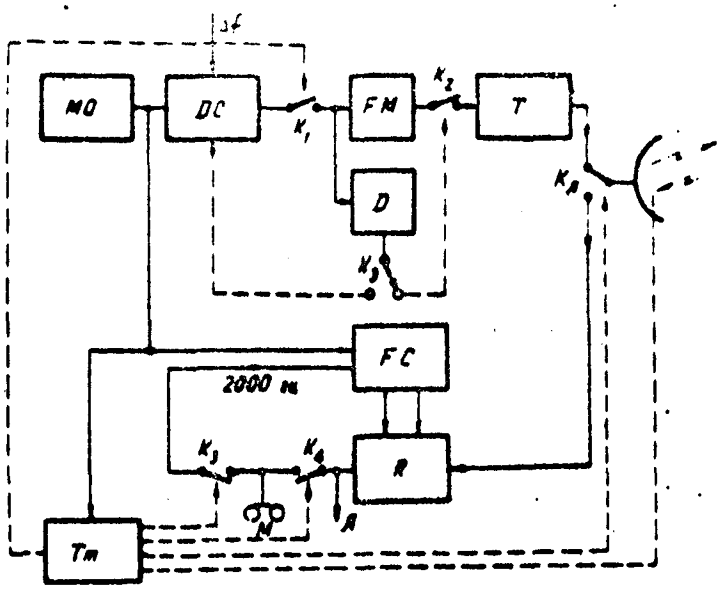

Fig 1

The incoming signals were received by a superheterodyne receiver having a semiconductor parametric amplifier. A counting down process in the received was so arranged that, depending on the value of the Astronomical Unit, the reflected signal should produce a frequency of about 720 to 750 c.p.s. at the output of the receiver if Venus did not rotate. This signal was recorded together with the noise on a magnetic tape in a 420 – 1020 c.p.s. band. A sine wave of 2000 c.p.s. was recorded on the same tape for checking and keeping the rate of the magnetic tape motion during reproduction. The recording of this sine-wave was started exactly at the instant at which according to calculations, the five-minute series of reflected signals were expected to arrive. This served to indicate the departure of the actual travel time of a signal to Venus and back again.

The diagram of the receiving part of the system is also shown in figure 1, where the designations are : R is the receiver, FC is the frequency convertor giving heterodyne frequencies for the receiver and also the 2000 c.p.s. frequency for the magnetic tape recorder M.

To stop the transmission cycle and to start the reception, the following technique is used : the timer T_m opens the key K_1 connecting the antenna to the receiver by means of the key K_A, changes the antenna polarization and feeds the oscillations to the tape recorder. At the beginning of the experiment the oscillations from the magnetic tape were analysed by means of ten filters, each having a pass band of 60 c.p.s., and all together covering the frequency range from 420 to 1020 c.p.s. An energy difference ΔW was determined at the output of each filter : $\Delta W = W' - W''$ where W' is the total energy of the oscillations at the output of the filter for time intervals hatched once in figure 2 ; W'' is a similar energy for intervals hatched twice.

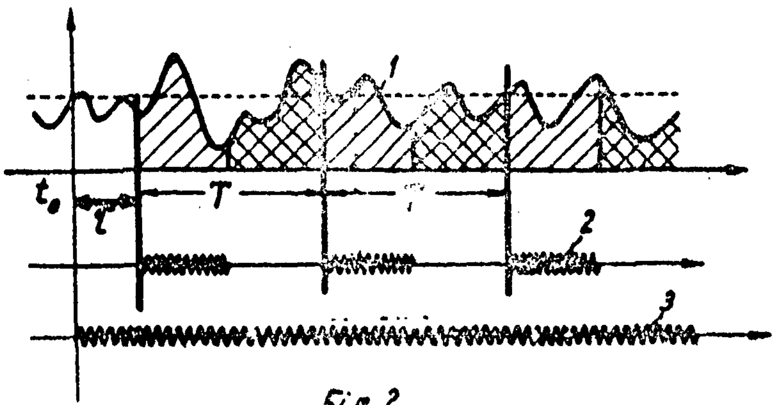

Fig. 2

In figure 2 the following designations are used : t_0 is the calculated time instant of the arrival of the train of reflected signals, i.e. the instant at which the recording of 2000 c.p.s. oscillations begins. T is the signal modulation period — 256 or 128 s; τ is the delay established at will ; I is the instantaneous power of the sum of reflected signals and noises ; 2 is the actually arriving reflected signal ; 3 are the 2000 c.p.s. oscillations.

In the case when the delay τ is such that the instant $t_0 + \tau$ corresponds to the actual instant of the train of reflected signals' arrival, such situation is presented in figure 2 : the energy W' is equal to the energy of the signal plus noise, and the energy W'' is equal to the energy of the noise only. In this case the difference ΔW is at the maximum, and corresponds to the energy of the reflected signals. Several samples with various τ were taken during the analysis. The modulation phase of the transmitted signals changed every other reception, and the sign of energy difference ΔW changed accordingly. This made the elimination of systematic errors possible.

A system having a diagram shown in figure 3 next page was used to analyze signals. Signals from the tape recorder M were fed to ten filters F_1, F_2 ..... F_{10} — resonant circuits — from the output of which they were fed to the RC device. If the voltage amplitude at the output of the filter exceeded a certain threshold, pulses applied from the divider D passed through the RC device onto counters C' and C". If the amplitude was less than this threshold, pulses did not pass through the RC device. The number of pulses applied to the RC device was 1000 per second. The number of pulses at the output of the RC device determined the energy of the oscillations which passed through the filter.

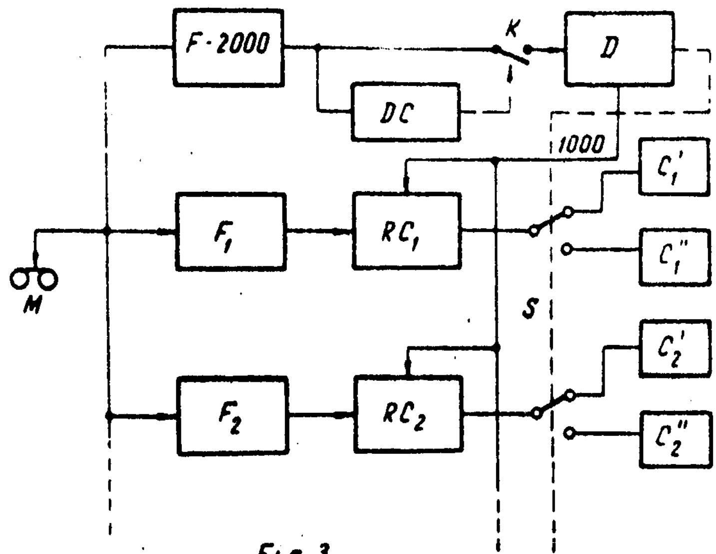

Fig 3

The oscillations with a frequency of 2000 c.p.s. recorded on tape were selected by the filter F — 2000 and got to the pulse counter DC which by counting the prescribed number of periods corresponding to the delay τ , closed the key K through which the oscillations of 2000 cps were applied to the divider D. This divider began to apply pulses to the device RC and to the switch S which worked with a modulation period of 256 or 128 milliseconds. This switch gave pulses in time intervals hatched once (see figure 2) upon counters C' which stored the energy W', and in time intervals hatched twice upon counters C" which stored the energy W". The difference of the readings of these counters gave the value ΔW at the output of each filter.

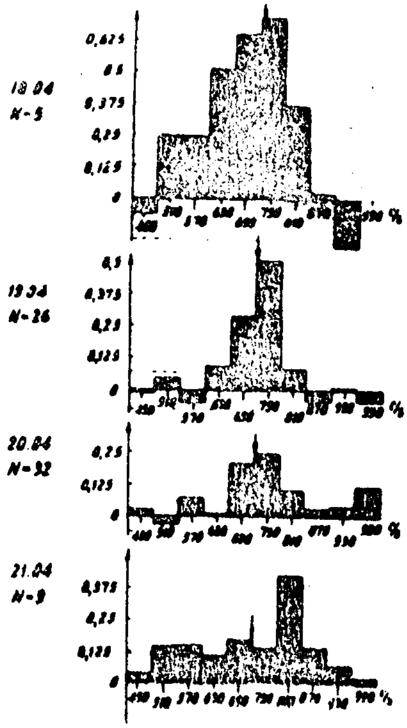

Fig 4

Figure 4 presents examples of the results of such processing for April 18, 19 20 and 21, 1961. The ratio of the power of the reflected signal signal in the given filter to the noise power of the 1 c/s band is given along the ordinate. Dotted lines indicate the values of the standard deviation which characterizes the accuracy of measurements.

On the basis of these results it is possible to estimate the maximum frequency shift of reflected signals, apparently caused by Venus' rotation, and to calculate the velocities causing it. These velocities turned out to be approximately equal to ~ 40 m/sec. If one assumes that the whole surface of the planet was reflecting, and that its axis was perpendicular to the direction of the radiation, then this velocity corresponds to the rotation period of approximately 11 days. If the rotation axis was 60° (this corresponds to Kuyper's data), this period should be about 9 – 10 days.

Having learned that the spectrum of signals reflected from Venus, as measured in the United States in 1961, was narrow, we carried out an analysis of recorded oscillations by a set of ten narrow filters with bandwidths of 4 c.p.s.

In this case the block-diagram shown in figure 5 was used for the analysis. It differs from the block-diagram of figure 3 by the following: filters F_1 .... F_{10} were multisection filters and they had a 4 c.p.s. band each. The counters C_1.... C_{10} were connected directly to the RC device. The oscillation applied to filters was interrupted with a period of the signal modulation by the key K up to filters. These alterations were made while taking into account that in the given case the nonstationary process in filters $F_1 \ldots F_{10}$ was of the same order as that of the modulation period. The key K turned to be closed for time intervals hatched once in figure 2 and was open at other times. Thus counters C recorded the energy W'. The same tape was played back for the second time, and the delay τ was increased by $\frac{T}{2}$. In this case the key K turned to be closed for the time intervals hatched twice, and the counters registered the values W''. Then the difference $\Delta W = W' - W''$ was taken.

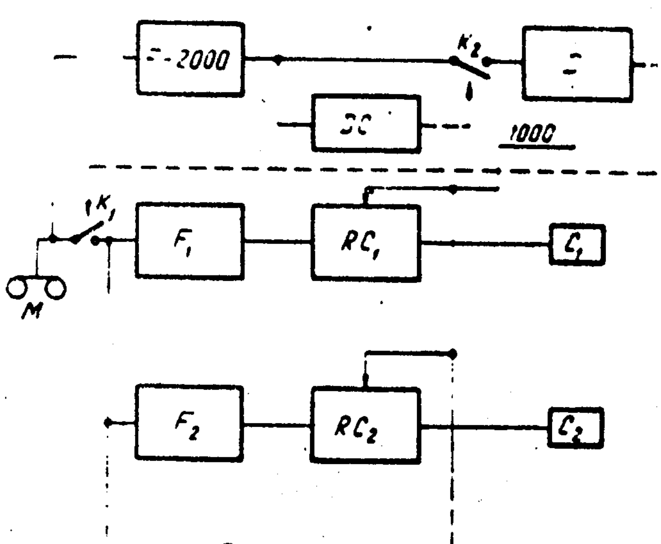

Fig.5

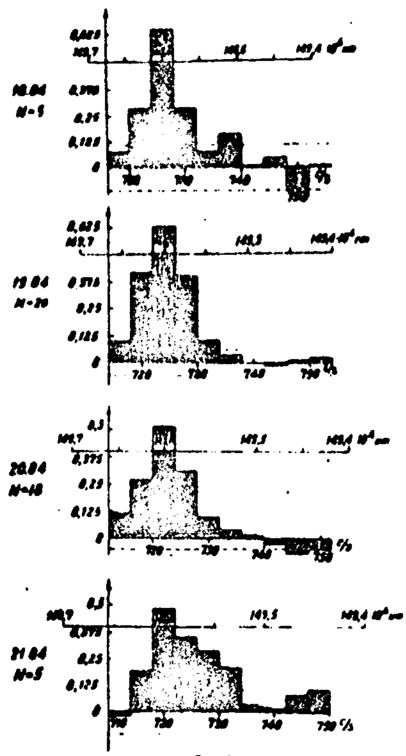

Fig 6

If the time instant $t_0 + \tau$ corresponded to the actual instant of the arrival of the train of reflected signals, the key in the first case would be closed during the time of the signal arrival, and W' would represent the total energy of the signal and of the noise. In the second case the key would be closed during pauses, and the signal — not applied to filters. Thus, W'' was equal to the noise energy. The difference $W = W' - W''$ with such a delay τ was maximum, and was equal to the energy of the signal.

The results of this analysis are presnted in figure 6, where values similar to those of the figure 4 are given along the abscissa and the ordinate. As is evident from this figure, there is a narrow spectral line near the center of the wide spectrum. In our experiments its width was apparently mainly caused by the signal modulation whose frequency for the given days was equal to 4 c.p.s.

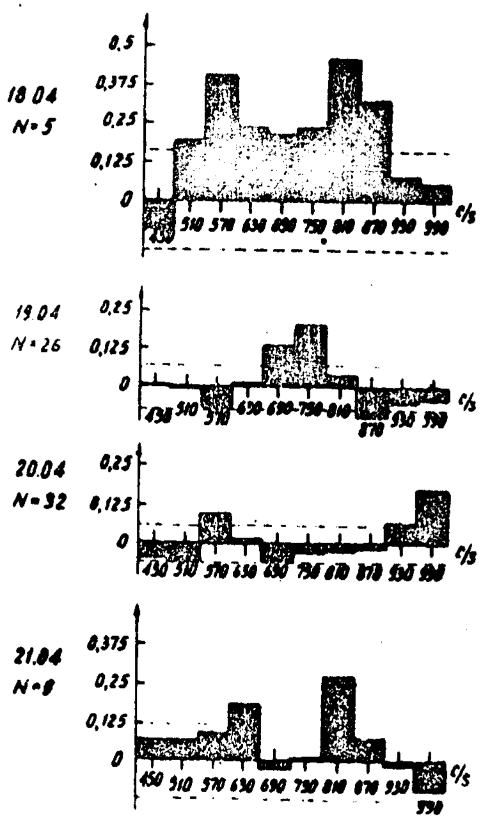

Fig 7

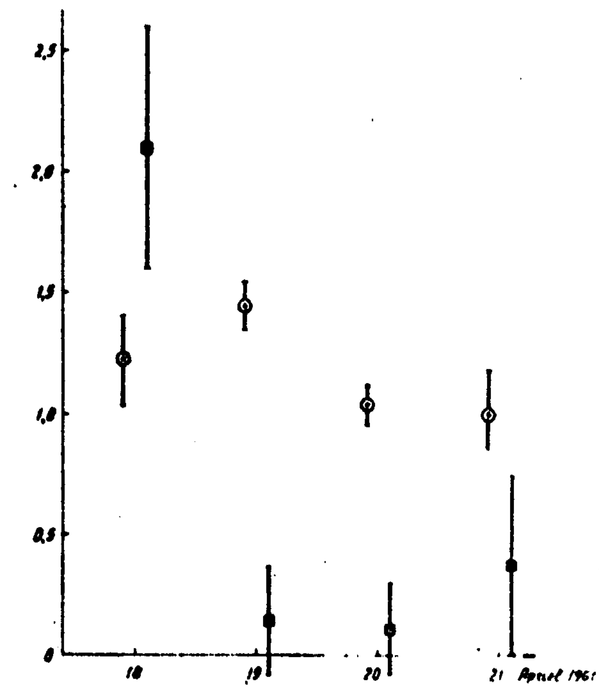

Fig 8

Figure 7 presents the values of the power only caused by the wide part of the spectrum's band. These values are obtained by means of the rejection filter*) which eliminated the part of the spectrum at the input of the analyzer comprising the narrow component.

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*) The rejection filter had the attenuation of 5 – 11 decobels in the band of ± 6 c.p.s.

Figure 8 presents the total average power of the narrow and wide spectra for a number of days. The values of the power of reflected signals related to the noise power in the band of 1 c.p.s. are given along the ordinate. Dots noted by ▣ correspond to the wide component of the spectrum. Dots designated by • correspond to the narrow component. The length of vertical lines drawn through these dots is equal to two standard deviations which took place in the given measurements. As is evident from this figure, the power of the narrow spectrum varied for some days rather little, but the power of the wide spectrum varied rather strongly on certain days, and the total power of the wide spectrum exceeded the power of the narrow spectrum.

The average reflectivity of a signal corresponding to the whole visual surface of Venus narrow spectrum was equal to 8%.

Taking into account that the width of the wide component of the spectrum is approximately by two orders greater than the width of the narrow component, and that their power is of the same order, we shall obtain that the spectral density in the wide component is about two orders of magnitude less than in the narrow component.

The results obtained may for example be explained in the following manner: The narrow component is caused by the reflection from the planetary point closest to the Earth for which there is no Doppler shift. If the planet were ideally flat, this component would be the only one to exist. The wide component is caused by scattered reflection from the whole surface, whose points give different Doppler shifts due to rotation.

The magnitude of the Astronomical Unit on the basis of measurements made may be obtained by two methods: Firstly, it can be obtained from the Doppler shift of the narrow line and, secondly — from the delay of the signal envelope.

Depending upon the assumed value of the Astronomical Unit, the calculated value of the center of the spectral line is different. Fig. 6 gives these values. As is evident from that figure, the Astronomical Unit should lie within the limits 149,590 — 149,610 thousand kilometers. Here, account has been taken that the instrumentation guaranteed the accuracy of the frequency within the limits of ±1 c.p.s. By measuring ΔW at different τ it is possible to determine the delay of the signal envelope in the path Earth – Venus – Earth, and to determine from it the value of the Astronomical Unit. These values are given in fig. 9. They have been obtained for separate receptions for April 18, 19, 20 and 21 from the signal concentrated in the narrow spectrum. The results for three filters with the width of 4 c.p.s. were combined. The average value of the Astronomical Unit obtained by this method resulted equal to 149,599,500 km *) with the mean square error about 600 km determined from the data obtained in different measurements. Besides, a systematic error should be added due to the fact that the delay of the signal in the transmission and reception channel was not taken into account with precision. The mean square value of this error may be taken equal to 0.7 mc/s or in the Astronomical Unit it is equal to 350 km.

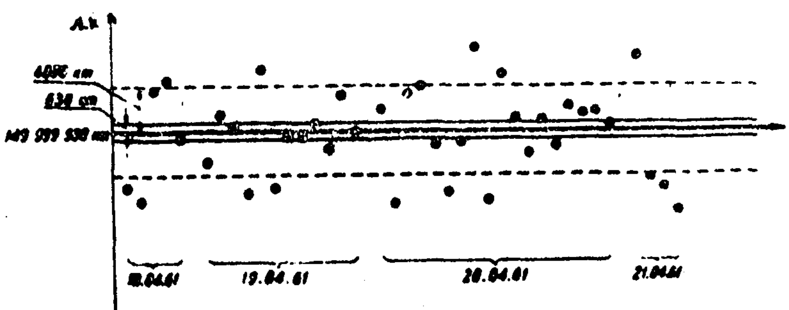

Fig.9

The value of the delay of signals and therefore of the Astronomical Unit may be also influenced by our imprecise knowledge of Venus' radius, by the additional delay of the signal in the Earth's and Venus' ionospheres and in interplanetary space due to the presence within them of free electrons, by our impr... knowledge about the location of the reflecting elements on Venus. Radius of Venus was taken in our calculations as equal to 5.100 km., and this gives an additional error of ~300 km, if we assume the possible error in radius estimation as being ~100 km. The Earth's ionosphere gives an additional delay of less than 0.01 millisecond at a frequency of 70 mc.p.s. The interplanetary space gives a delay of 0.03 milliseconds, if we assume that the electron concentration in it

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*) The speed of light was taken at 299 792.5 km/sec.

even equal to 1 000 el per cm^3, gives a delay of 0.03 milliseconds. Thus we assume that the Venus ionosphere is approximately the same as that of the Earth, the total additional delay being less than 0.06 ms which can reduce the value of the Astronomical Unit by less than 30 km. At last, the narrow component of the spectrum is approximately by two orders of magnitude narrower than the wide component. It follows therefrom that the radius of the reflecting spot responsible for the narrow component of the spectrum should also about two orders of magnitude lower than the Venus' radius, i. e. it cannot considerably exceed 100 km. If the surface is flat, the points of such a spot will be at a distance to the North whose difference should not exceed 1 km, which may entail an error of 3 km in Astronomical Unit's value. The existence of mountains on Venus apparently might also influence insignificantly the value of the Astronomical Unit. Thus, the total mean-square error in the Astronomical Unit may be estimated by the value

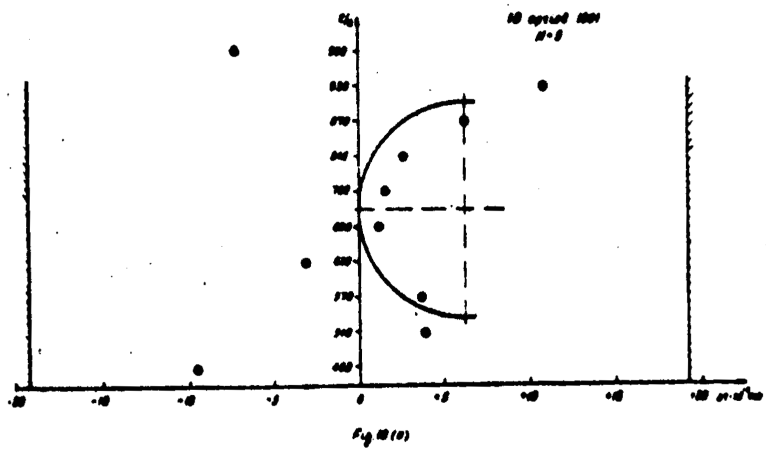
$$\sqrt{600^2 + 350^2 + 300^2} = 750 \text{ km.}$$

Here the error of ephemeris should be added. This error is estimated at 220 kms. Then, the mean square error determining the Astronomical Unit will be

$$\sqrt{750'' + 220^2} = 800 \text{ km.}$$

The delay of the signal determined by the method used in the present work is not unique : it can be greater or lower by the signal period multiplied by an interval with a period of 256 milliseconds. This gives the value of the Astronomical Unit of about 149,469,500, 149,599,500 and 149,729,500 km. Because onle one of these values is not in contradiction with figure 6, it is chosen as adequate. This value is 149,599,500 km.

Fig. 10 gives the distance to Venus obtained from the delay of the signal envelope in various filters with a 60 c.p.s. band. With the help of rejection filters the part of the spectrum at the input of the analyzer comprising the narrow component was eliminated. In this figure the difference in distances to Venus from the signal in the given filter, and from the signal in the narrow spectrum (it should give the distance to the point closest to Earth) is plotted along the abscissa, and the filters' frequencies are plotted along the ordinate.



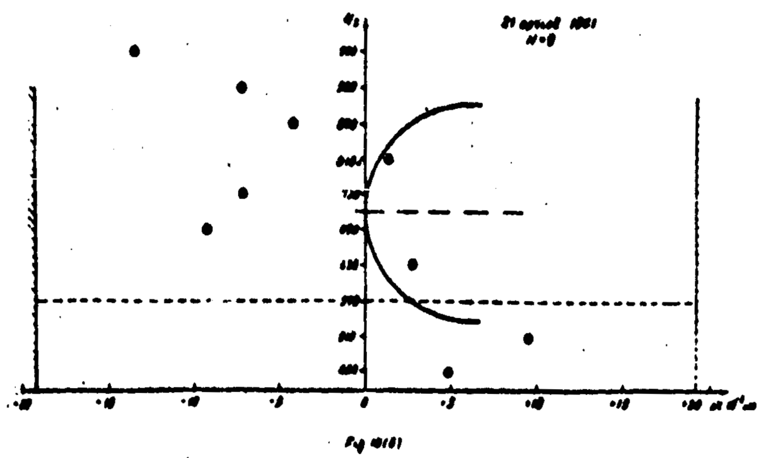


Fig. 10. Distance to Venus obtained from the Delay of the Wide Spectrum Component of the Signal selected by various Filters.

*** END ***